

COOL-COLOR ROOFING MATERIAL ATTACHMENT 13: TASK 2.7.3 REPORTS - CODE REVISIONS



Arnold Schwarzenegger
Governor

PIER FINAL PROJECT REPORT

Prepared For:

California Energy Commission
Public Interest Energy Research Program

Prepared By:

**Lawrence Berkeley National Laboratory
and Oak Ridge National Laboratory**



**ERNEST ORLANDO LAWRENCE
BERKELEY NATIONAL LABORATORY**

June 2006
CEC-500-2006-067-AT13



Prepared By:

Lawrence Berkeley National Laboratory
Hashem Akbari
Berkeley, California
Contract No. 500-01-021

Oak Ridge National Laboratory
William Miller
Oak Ridge, Tennessee

Prepared For:

California Energy Commission
Public Interest Energy Research (PIER) Program

Chris Scruton
Contract Manager

Ann Peterson
Building End-Use Energy Efficiency Team Leader

Nancy Jenkins
PIER Energy Efficiency Research Office Manager

Martha Krebs, Ph.D.
Deputy Director
**ENERGY RESEARCH AND DEVELOPMENT
DIVISION**

B. B. Blevins
Executive Director

DISCLAIMER

This report was prepared as the result of work sponsored by the California Energy Commission. It does not necessarily represent the views of the Energy Commission, its employees or the State of California. The Energy Commission, the State of California, its employees, contractors and subcontractors make no warrant, express or implied, and assume no legal liability for the information in this report; nor does any party represent that the uses of this information will not infringe upon privately owned rights. This report has not been approved or disapproved by the California Energy Commission nor has the California Energy Commission passed upon the accuracy or adequacy of the information in this report.

Estimates of Energy-Savings for Cool Colored Residential Roofs in California

Hashem Akbari
Heat Island Group
Lawrence Berkeley National Laboratory
Berkeley, California 94720

May 2005

This work was supported by the California Energy Commission (CEC) through its Public Interest Energy Research Program (PIER), and by the Assistant Secretary for Renewable Energy under Contract No. DE-AC03-76SF00098.

Estimates of Energy-Savings for Cool Colored Residential Roofs in California

H. Akbari
Heat Island Group
Environmental Energy Technologies Division
Lawrence Berkeley National Laboratory

1. Introduction

Raising the solar reflectance of a roof from a typical value of 0.1–0.2 to an achievable 0.6 can reduce cooling-energy use in buildings by more than 20%. Cool roofs also reduce ambient outside air temperature, thus further decreasing the need for air conditioning and retarding smog formation.

We are collaborating with pigment manufacturers to characterize colorants, and with manufacturers of roofing materials to produce cool colored products, including asphalt shingles, concrete and clay tiles, metal roofing, wood shakes, and coatings. In this collaboration, we have identified and characterized pigments suitable for cool-colored coatings, and developed engineering methods for applying cool coatings to roofing materials. We are also measuring and documenting the laboratory and *in-situ* performances of roofing products. Demonstration of energy savings can accelerate the market penetration of cool-colored roofing materials. Early results from this effort have yielded colored concrete, clay, and metal roofing products with solar reflectances exceeding 0.4. Obtaining equally high reflectances for roofing shingles is more challenging, but some manufacturers have already developed several cost-effective colored shingles with solar reflectances of at least 0.25.

One of the project tasks (Task 2.7.3) was to develop preliminary estimates of cooling electricity savings and potential heating energy penalties resulting from the installation of cool colored roofing materials on residential buildings in California. To accomplish this objective, we simulated the cooling and heating energy use of a prototypical building for 16 California climate zones. This brief report highlights the characteristics of the prototype buildings and summarizes the results of the simulations.

2. Residential Building Descriptions

The prototype residential building was modeled as a single-story single-family detached structure. Changing the reflectance of the roof affects the heat transfer through the roof structure. Therefore, we focused on prototypical simulations of the upper floor, which captures the effects of changes in roof reflectance. The average roof area selected for these prototypical simulations was 1600 ft².

The roof was constructed with asphalt shingles on a 20° sloped plywood deck, over a naturally ventilated and unconditioned attic, above a studded ceiling frame with fiberglass insulation (varying by vintage), and with a sheet of drywall beneath. The fractional-leakage-area of the attic and living quarters depended on vintage. Variable air infiltration was modeled by the

Sherman-Grimsrud algorithm (Sherman 1986). The existing solar reflectance of the roof was selected to be 0.1, typical for dark asphalt shingles, and the albedo of the reflective roof was taken to be 0.3. The thermal emittance of each roof was 0.9.

The residence was cooled and heated by a central air-conditioning system with ducts located in the attic space, with a constant volume fan, and without an economizer. Heating was modeled once with a gas furnace and again with an electric heat pump. Cooling by natural ventilation was available by window operation. The systems were sized based on peak cooling and heating loads as determined by DOE-2. System component efficiencies were selected for each vintage. A Seasonal Energy Efficiency Ratio (SEER) of 8.5 and 10 was assumed for the central air-conditioner of the pre-1980 and 1980⁺ buildings, respectively. Also a Heating Season Performance Factor (HSPF) of 5 and 7 was assumed for the stock of old and new residential central electric heat pumps.

Modified part-load-ratio curves for a typical air-conditioner, heat pump, and gas furnace were used in place of the standard DOE-2 curves, as they have been shown to model low-energy use more accurately (Henderson 1998). Duct loads were simulated with a validated residential duct function (Parker *et al.* 1998) implemented into DOE-2 to better estimate the thermal interactions between the ducts and space. The function was designed for the residential central system type (RESYS) in DOE-2 and for a single air-conditioned living space with an attic and basement. Since this function greatly improves cooling- and heating-energy use estimates, and the top story of a building receives the bulk of the benefits of a reflective roof, the single-story residential structure was modeled.

Building data for residences are shown in **Table 1** and were obtained from several sources. We used existing data to characterize the existing stock of pre-1980 buildings (Konopacki *et al.*, 1997). Characteristics for 1980⁺ construction homes were identified from DOE national appliance energy standards (NAECA 1987), California Energy Commission prototypes (CEC 1994), and Energy Star® (USDOE 2001).

3. Solar-Reflectance of Cool Colored Roofs

To simulate the effect of cool colored materials, the values of roof albedo were chosen to be 0.1 for the base case (representing dark colored fiberglass asphalt shingles) and 0.3 for the cool case (representing colored cool shingles). The thermal emittance of each material was 0.9. In DOE-2 the *ABSORPTANCE* keyword for roof construction was 0.9 (solar reflectance 0.1) for the basecase and was changed to 0.7 (solar reflectance 0.3). To estimate savings from increased roof reflectance ($\Delta\rho$) other than the differential specified in the tables, multiply the savings by the ratio $\Delta\rho/0.2^*$.

We estimated the cooling electricity savings and heating energy penalties for various levels of roof insulation: R-5, R-7, R-11, R-19, and R-30 for pre-1980 prototypes; and R-11, R-19, R-30, R38, and R-49 for 1980⁺ prototypes.

* Linear interpolation can be used to estimate savings or penalties for net changes in roof solar reflectance ($\Delta\rho_2$) other than that used in the simulations ($\Delta\rho_1$) (Konopacki *et al.* 1997). Therefore, these results can be simply multiplied by the ratio $\Delta\rho_2/\Delta\rho_1$ to obtain estimates for other roof reflectance scenarios.

3. Weather Data

We used the California Energy Commission CTZ (California Thermal Zone) climate descriptions to simulate the cool-roof savings from in each of 16 zones. **Table 2** shows the number of cooling and heating degree days in each zone.

4. Simulation results

Tables 3-6 summarize the results of the simulations. For most California climates, the application of cool colored roof yields net savings in the range of 100-400 kWh per 1000 ft² per year. The savings are obviously smaller for buildings with higher roof insulation.

The results presented in Tables 3-6 also apply to flat cool colored concrete and clay tiles. For most clay tiles, the base-case solar reflectance is about 0.2 and the cool-case solar reflectance is 0.4.

5. Summary

We have performed building energy simulations for a prototype residential building in 16 California Climate zones. Cool colored roofing materials can increase the solar reflectance of the roofs by about 0.2. Such an increase in solar reflectance of the roof will result in cooling energy savings in the range of 100-400 kWh per 1000 ft² per year.

6. Acknowledgement

This work was supported by the California Energy Commission (CEC) through its Public Interest Energy Research Program (PIER), by the Laboratory Directed Research and Development (LDRD) program at Lawrence Berkeley National Laboratory (LBNL), and by the Assistant Secretary for Renewable Energy under Contract No. DE-AC03-76SF00098. The authors wish to thank CEC Commissioner Arthur Rosenfeld and PIER managers Nancy Jenkins and Chris Scruton for their support and advice.

5. References

- Building Energy Simulation Group (BESG). 1990. "Overview of the DOE-2 Building Energy Analysis Program, Version 2.1D." Lawrence Berkeley National Laboratory Report LBL-19735, Rev. 1. Berkeley, CA.
- California Energy Commission (CEC). 1994. "Technology Energy Savings Volume II: Building Prototypes," California Energy Commission Report P300-94-007, Sacramento, CA.
- Henderson, H. 1998. "Part Load Curves for Use in DOE-2." Draft report prepared for Lawrence Berkeley National Laboratory and Florida Solar Energy Center. CDH Energy Corp. Cazenovia, NY. January 16, 1998.
- Konopacki, S., H. Akbari, M. Pomerantz, S. Gabersek and L. Gartland. 1997. "Cooling Energy Savings Potential of Light-Colored Roofs for Residential and Commercial Buildings in 11 US Metropolitan Areas." Lawrence Berkeley National Laboratory Report LBNL-39433. Berkeley, CA.
- National Appliance Energy Conservation Act of 1987 (NAECA). 1987.

- Parker, D., J. Huang, S. Konopacki, L. Gartland, J. Sherwin and L. Gu. 1998. "Measured and Simulated Performance of Reflective Roofing Systems in Residential Buildings." *ASHRAE Transactions* **104**(1):963-975.
- Sherman, M., D. Wilson and D. Kiel. 1986. "Variability in Residential Air Leakage." Measured Air Leakage in Buildings ASTM STP-904. Philadelphia, PA.
- US Department of Energy (USDOE). 2001. "Choosing or Upgrading Your Central Air Conditioner." Office of Building Technology, State and Community Programs". http://www.eren.doe.gov/buildings/heatcool_cenair.html.
- Winklemann, F., B. Birdsall, W. Buhl, K. Ellington and A. Erdem. 1993. "DOE-2 Supplement Version 2.1E." Lawrence Berkeley National Laboratory Report LBNL-34947. Berkeley, CA.

Table 1. Prototypical building description for single-family residence.

Single-Family Residence	Pre-1980	1980⁺
single-story, non-directional		
roof & floor area (ft ²)	1,600	
Zones		
living (conditioned)		
attic (unconditioned)		
basement (unconditioned)		
Roof Construction		
20° slope		
¼" asphalt shingle		
¾" plywood deck w/ 2" x 6" rafters		
naturally ventilated attic		
¾" plywood deck w/ 2" x 6" rafters (15%)		
fiberglass insulation (85%)	parametric	parametric
½" drywall		
Roof Solar Reflectance		
pre	0.1	
post	0.3	
Roof Thermal Emittance	0.9	
Wall Construction		
brick exterior		
wood frame (15%)		
fiberglass insulation (85%)	R-5	R-13
½" drywall interior		
Windows		
clear with operable shades		
number of panes	1	2
window to wall ratio	0.18	
Fractional Leakage Area (in²/100 ft²)		
living	4	2
attic	8	4
Air-conditioning equipment		
central a/c, direct expansion, air-cooled		
seasonal energy efficiency ratio (SEER)	8.5	10
coefficient of performance (COP)	2.5	2.9
cooling setpoint (°F)	78	
natural ventilation available		
Heating Equipment		
1) central forced air gas furnace		
efficiency (%)	70	78
heating setpoint (°F)	70	
11pm - 7am setback (°F)	60	
2) central electric heat pump		
heating season performance factor (HSFP)	5	7
Duct Air Leakage (%)	20	10

Table 2. Heating and Cooling Degree Days (base 65) for each California Thermal Zone (CTZ).

Climate Zone	City	HDD65	CDD65
CTZ1	Arcata	3933	0
CTZ2	Santa Rosa	3073	482
CTZ3	Oakland	2588	50
CTZ4	Sunnyvale	2367	351
CTZ5	Santa Maria	2504	49
CTZ6	Los Angeles	1521	389
CTZ7	San Diego	1292	547
CTZ8	El Toro	1424	808
CTZ9	Pasadena	1361	1035
CTZ10	Riverside	1674	1363
CTZ11	Red Bluff	2709	1408
CTZ12	Sacramento	2675	871
CTZ13	Fresno	2237	2029
CTZ14	China Lake	2979	1858
CTZ15	El Centro	875	4156
CTZ16	Mount Shasta	5414	292

Table 3. Estimates of annual cooling electricity savings (kWh) and heating energy penalties (therms) from installation of cool-colored roofs on pre-1980 single-family detached homes with gas furnace heating systems. All savings and penalties are per 1000 ft² of roof area. Solar reflectance change is 0.2 (for fiber glass asphalt shingles: change of the roof reflectance from 0.1 to 0.3; for clay and concrete tiles: change of the roof reflectance from 0.2 to 0.4). The savings and penalties can be linearly adjusted for other values of changes in solar reflectance.

Roof Insulation	R-5		R-7		R-11		R-19		R-30	
	Cooling (kWh)	Heating (therms)	Cooling (kWh)	Heating (therms)	Cooling (kWh)	Heating (therms)	Cooling (kWh)	Heating (therms)	Cooling (kWh)	Heating (therms)
Climate Zone										
CTZ1	110	-11	90	-9	67	-7	47	-5	35	-5
CTZ2	172	-9	149	-7	120	-6	93	-4	76	-3
CTZ3	117	-8	97	-6	73	-5	52	-4	39	-3
CTZ4	155	-7	133	-6	106	-5	80	-3	65	-3
CTZ5	116	-8	96	-6	73	-5	51	-3	39	-3
CTZ6	160	-5	137	-4	110	-3	84	-2	68	-2
CTZ7	181	-5	157	-4	127	-3	99	-2	82	-1
CTZ8	214	-5	188	-4	156	-3	124	-2	104	-1
CTZ9	244	-5	215	-4	180	-3	146	-2	124	-1
CTZ10	286	-6	255	-5	216	-3	177	-2	152	-2
CTZ11	292	-8	260	-7	221	-5	182	-4	156	-3
CTZ12	223	-8	196	-7	162	-5	130	-4	110	-3
CTZ13	372	-7	336	-6	289	-4	241	-3	209	-2
CTZ14	350	-9	315	-7	270	-6	225	-4	195	-3
CTZ15	646	-4	593	-3	521	-2	445	-1	393	-1
CTZ16	148	-14	126	-12	99	-10	75	-8	60	-6

Table 4. Estimates of annual cooling electricity savings (kWh) and heating energy penalties (therms) from installation of cool-colored roofs on 1980⁺ single-family detached homes with gas furnace heating systems. All savings and penalties are per 1000 ft² of roof area. Solar reflectance change is 0.2 (for fiber glass asphalt shingles: change of the roof reflectance from 0.1 to 0.3; for clay and concrete tiles: change of the roof reflectance from 0.2 to 0.4). The savings and penalties can be linearly adjusted for other values of changes in solar reflectance.

Roof Insulation Climate Zone	R-11		R-19		R-30		R-38		R-49	
	Cooling (kWh)	Heating (therms)	Cooling (kWh)	Heating (therms)	Cooling (kWh)	Heating (therms)	Cooling (kWh)	Heating (therms)	Cooling (kWh)	Heating (therms)
CTZ1	43	-4	29	-3	21	-2	18	-2	15	-2
CTZ2	73	-3	54	-2	42	-2	38	-2	34	-1
CTZ3	46	-3	32	-2	23	-1	20	-1	17	-1
CTZ4	65	-3	47	-2	36	-1	33	-1	29	-1
CTZ5	46	-3	32	-2	23	-1	20	-1	17	-1
CTZ6	67	-2	49	-1	38	-1	34	-1	30	0
CTZ7	77	-2	58	-1	45	-1	41	0	37	0
CTZ8	93	-2	71	-1	57	-1	51	-1	47	0
CTZ9	107	-2	83	-1	67	-1	61	0	55	0
CTZ10	127	-2	100	-1	81	-1	74	-1	68	-1
CTZ11	130	-3	102	-2	83	-1	76	-1	70	-1
CTZ12	97	-3	74	-2	59	-1	54	-1	49	-1
CTZ13	168	-2	134	-2	111	-1	102	-1	94	-1
CTZ14	158	-3	125	-2	103	-2	95	-1	87	-1
CTZ15	300	-1	244	-1	206	0	190	0	176	0
CTZ16	61	-6	44	-4	34	-3	30	-3	27	-3

Table 5. Estimates of annual cooling electricity savings (kWh) from installation of cool-colored roofs on pre-1980 single-family detached homes with electric heat pump heating systems. All savings and penalties are per 1000 ft² of roof area. Solar reflectance change is 0.2 (for fiber glass asphalt shingles: change of the roof reflectance from 0.1 to 0.3; for clay and concrete tiles: change of the roof reflectance from 0.2 to 0.4). The savings and penalties can be linearly adjusted for other values of changes in solar reflectance.

Roof Insulation	R-5	R-7	R-11	R-19	R-30
Climate Zone	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)
CTZ1	-178	-184	-189	-185	-181
CTZ2	-79	-90	-100	-105	-108
CTZ3	-168	-174	-179	-177	-174
CTZ4	-106	-115	-124	-127	-128
CTZ5	-168	-175	-180	-177	-174
CTZ6	-98	-108	-118	-121	-122
CTZ7	-66	-77	-89	-95	-98
CTZ8	-12	-26	-41	-51	-58
CTZ9	34	19	1	-14	-23
CTZ10	102	83	61	40	28
CTZ11	111	92	69	48	34
CTZ12	1	-13	-29	-41	-48
CTZ13	239	214	183	150	130
CTZ14	203	180	151	122	103
CTZ15	676	631	572	502	456
CTZ16	-118	-127	-135	-137	-137

Table 6. Estimates of annual cooling electricity savings (kWh) from installation of cool-colored roofs on 1980⁺ single-family detached homes with electric heat pump heating systems. All savings and penalties are per 1000 ft² of roof area. Solar reflectance change is 0.2 (for fiber glass asphalt shingles: change of the roof reflectance from 0.1 to 0.3; for clay and concrete tiles: change of the roof reflectance from 0.2 to 0.4). The savings and penalties can be linearly adjusted for other values of changes in solar reflectance.

Roof Insulation	R-11	R-19	R-30	R-38	R-49
Climate Zone	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)
CTZ1	-75	-70	-64	-62	-59
CTZ2	-28	-30	-30	-29	-28
CTZ3	-70	-66	-61	-58	-55
CTZ4	-41	-41	-39	-38	-36
CTZ5	-70	-66	-61	-58	-56
CTZ6	-37	-38	-36	-35	-34
CTZ7	-22	-24	-25	-25	-24
CTZ8	4	-3	-6	-7	-7
CTZ9	26	16	10	8	7
CTZ10	57	43	34	30	28
CTZ11	62	47	37	33	30
CTZ12	10	2	-2	-3	-4
CTZ13	122	98	82	75	70
CTZ14	105	84	69	64	59
CTZ15	328	274	235	219	204
CTZ16	-47	-46	-43	-42	-40